

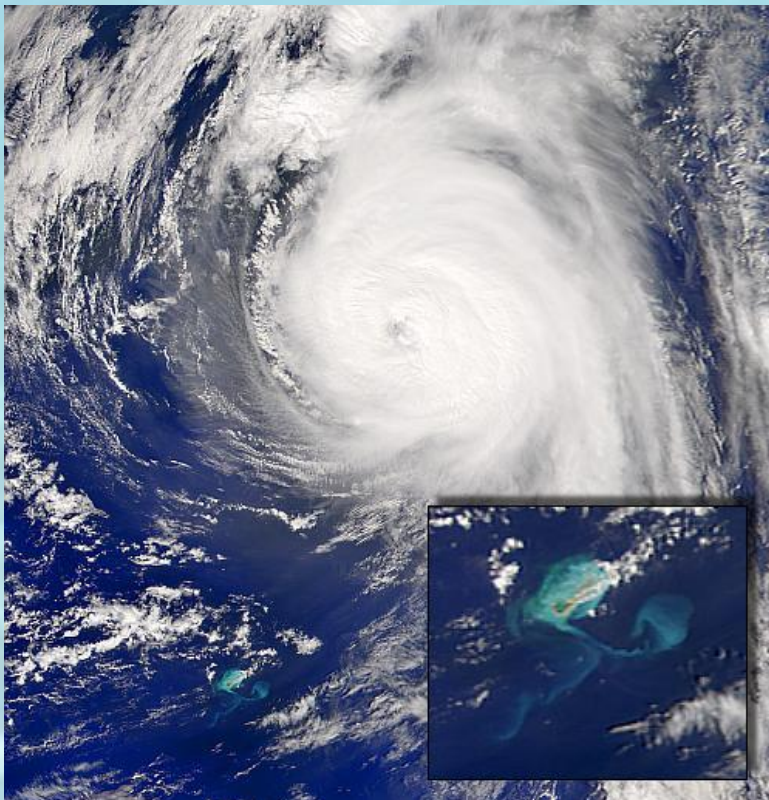
SCIENCE FOCUS: Marine Sediments

State of (Re) Suspense

What comes to mind when you hear the name "Fabian"?

Many baby-boomers in the United States will probably think of a 1950s and 1960s pop music star, who frequently appeared on "American Bandstand" singing hits like "I'm a Man" and "Tiger". Fabian also appeared in a movie that was one of the best in its genre (surfing movies), [*Ride the Wild Surf*](#). (For trivia buffs, the movie also featured James Mitchum, Australian swimming star Murray Rose, Shelly Fabares and Barbara Eden.)

However, if both Fabian and wild surf are mentioned to residents of the island of Bermuda, they are probably more likely to think of Hurricane Fabian, a Category 3 hurricane that smashed the island with a nearly direct hit on September 5, 2003. The day after the passage of Fabian over Bermuda, the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) acquired this image. The island of Bermuda as at lower left, and the excerpt at lower right is a magnification of the island of Bermuda.



SeaWiFS image of Hurricane Fabian and Bermuda, acquired on September 6, 2003.

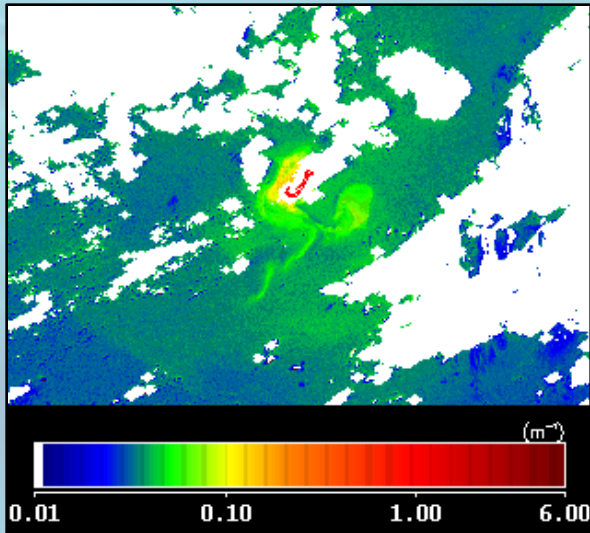
The image excerpt shows a very large plume of sediments originating on the island and extending to the south, splitting into two distinct parts. The winds and wild surf of Fabian caused extensive erosion of the Bermuda beaches, and the hurricane also did something else: it stirred up the carbonate sediments lying in the large lagoon that lies north of the island. This combination of beach sand and lagoon sediments is the material in the sediment plume emanating from the island.

A general definition of sediments is particulate material found on the bottom (marine scientists use the term "benthic zone") of a body of water (an ocean, lake, or pond, or even the bottom of a hot water tank in a house). "Suspended sediments" are particulate materials (usually inorganic mineral grains) in the water column above the bottom. Though they are usually sinking in the water, wave and wind action can keep heavy mineral grains in the water for a longer period of time than if they were sinking in calm water. "Neritic sediments" are sediments found in shallow coastal waters.

Waves and wind, particularly wild surf from a hurricane like Fabian (note: this is the last appearance of the phrase "wild surf") can also cause the sediments which have lying on the bottom to be suspended again, or resuspended. The sediments in the plume generated by Fabian are a mixture of "new" sedimentary material (beach sand) and resuspended sediments from the Bermuda lagoon.

Though it is not as widely known as the chlorophyll concentration data product that is widely used by biological oceanographers, the SeaWiFS Project produces a data product named K(490), which is defined as the "diffuse attenuation coefficient at 490 nanometers". 490 nm is the spectral location of one of the 8 SeaWiFS radiometric bands. K(490) provides a way to determine how rapidly light is "attenuated" (reduced) by material in the water column. Higher values of K(490) indicate that there are higher concentrations of material. [The units of K(490) are inverse meters, i.e., m^{-1} .] This material can be either inorganic sediments or either living or dead organic matter.

The image below is the K(490) data for the plume of sediments generated by Fabian from Bermuda. The highest K(490) values are actually north of the island, in the lagoon and in the waters adjacent to the lagoon. The eye of Fabian passed just barely to the west of Bermuda, moving in a northwesterly direction, so the last strong wind direction from the storm was actually from the northeast, pushing the resuspended sediments southwest of the island.



Diffuse attenuation coefficient at 490 nm, [K(490)] image of the island of Bermuda, showing high values in the sediment plume generated by Fabian.

When the high winds of hurricanes blow over relatively shallow waters, they will frequently resuspend benthic sediments, and the water doesn't have to be very shallow if the winds are strong enough. In 1999, Hurricane Floyd went over the Bahamas and then stayed out to sea along the continental shelf on the east coast of the United States before coming inland in the Carolinas. This track allowed Floyd to stir up the sediments on the continental shelf, as deep as 200 meters. In fact, the SeaWiFS image at left, acquired the day after Hurricane Floyd went onshore, provides a very clear indication of the continental shelf edge!



SeaWiFS image of Hurricane Floyd and the east coast of the United States acquired on September 16, 1999. The gray-green color offshore of the coast indicates a large amount of sediment suspension.

Tropical weather systems (hurricanes and typhoons) are capable of moving large amounts of neritic sediments. Before SeaWiFS was launched, a paper by J.G. Acker, C.W. Brown, and A.C. Hine indicated that it would be feasible to observe neritic sediment transport using remote sensing satellites. Although it took a few years to detect such events, during the active 2004 Atlantic hurricane season, hurricanes Charley and Frances impacted coastal areas of Cuba, Florida, and the Bahamas, resuspending and transporting large masses of sediment in these regions.

Effects of Hurricane Charley on Cuba



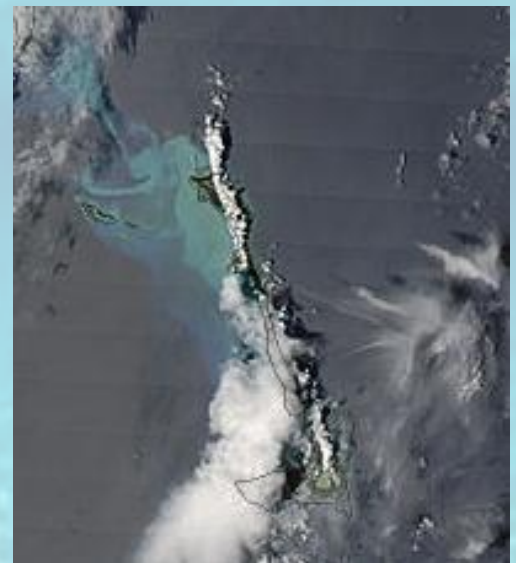
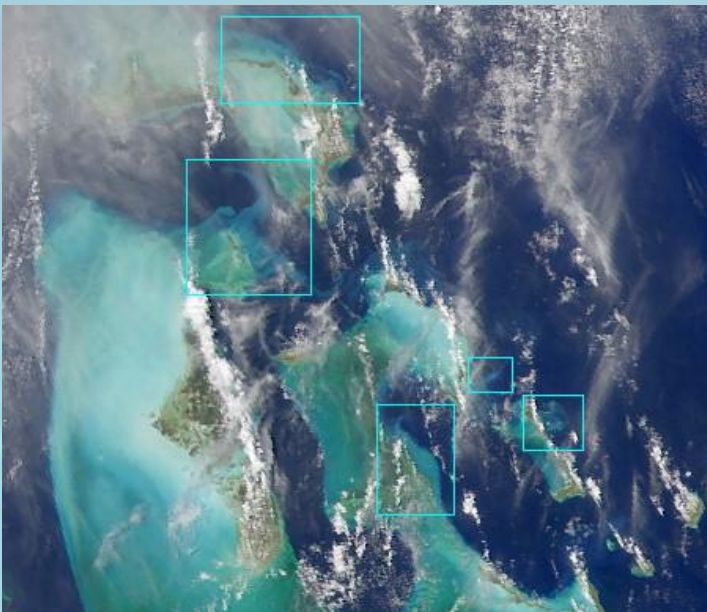
SeaWiFS and MODIS images of the Gulf of Batabano, Cuba, showing sediment resuspension due to passage of Hurricane Charley over this region. (Top left) SeaWiFS image of the Gulf of Batabano acquired August 11, 2004, before the passage of Charley. (Top right) SeaWiFS image of the Gulf of Batabano acquired on August 13, 2004, after the passage of Charley. Note the altered color of the shallow Gulf waters due to sediment resuspension. (Bottom) MODIS 500m resolution image of the Gulf of Batabano acquired on August 14, showing the persistence of sediment resuspension.

Effects of Hurricane Charley on Florida



SeaWiFS images of southwest Florida, the Florida Keys, and the Dry Tortugas, showing the effects of the winds of Hurricane Charley on neritic sediments. (Left) SeaWiFS image acquired August 11, 2004, before the passage of Charley. (Right) SeaWiFS image acquired August 14, 2004, after the passage of Charley. Bright blue-green waters are evident along the Keys, with an arrow-shaped plume of sediments near the Dry Tortugas, and significant resuspension along on the shallow West Florida Shelf off the southwest coast of Florida. The right image has lower resolution due to the positioning of this region in the SeaWiFS scanning swath; on August 14, the region was near the edge of the swath, so each pixel was larger than the pixels near the center of the swath, where the region was situated on August 11.

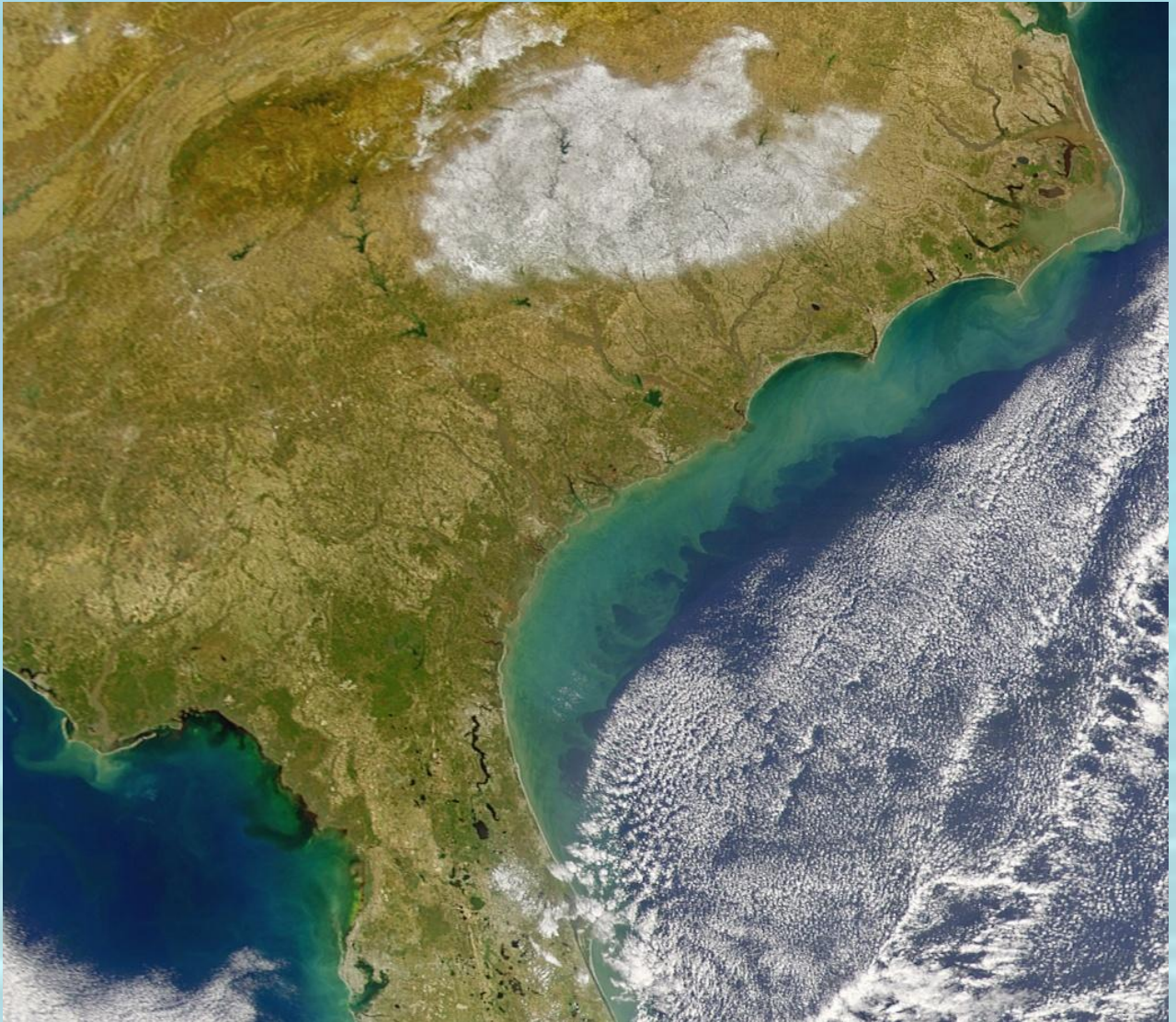
Effects of Hurricane Frances on the Bahamas



SeaWiFS and MODIS images showing the effects of Hurricane Frances on the Bahamas Banks. (Top left) SeaWiFS image of the Bahamas acquired on June 1, 2004, shown here for comparison. (Bottom left) SeaWiFS image of the Bahamas Banks acquired on September 6, 2004, showing several areas of sediment transport from the banks (blue boxes). Click on each of these images for the full-size image. (Top right) MODIS 500m resolution image acquired on September 6, 2004, with a higher resolution view of the sediments being transported from northeastern Grand Bahama Bank. (Bottom right) MODIS 500m resolution image of Cat Island, showing sediment transport to the west of the island. In the September 6 SeaWiFS image, sediments from Cat Island (box in bottom right corner) are also being transported to the east, indicating how shifts in wind direction affect the movement of resuspended sediments.

A Cold Wind over the Carolinas

Although hurricanes and typhoons may get the most attention from the media and meteorologists, other storms are sufficiently powerful to cause sediment resuspension. In late February 2004, a strong "nor'easter" deposited a large amount of snow in the Carolinas. When it moved offshore, it resuspended sediments along the coasts of Georgia and the Carolinas.



SeaWiFS image of the southeastern coast of the United States, showing snow (white area, top center) from a winter storm that caused significant sediment resuspension on the continental shelf off of Georgia and the Carolinas.

Why are suspended sediments important?

There are a number of reasons that resuspended sediments are an important topic in marine geology and marine chemistry. One of the most notable reasons is that resuspended sediments are one of the main source materials that builds barrier-island beaches. Waves and wind move sediments, i.e., sand, to areas where they accumulate, forming islands. Unfortunately, the tendency of waves and wind to move sediments gets interrupted when solid foundations and structures are built on barrier islands, leading to enhanced erosion of the beaches. In many beach areas, mankind has had to step in and artificially resuspend the sediments by dredging and then dumping sand from offshore on the beaches to keep them from disappearing completely.

Another reason that resuspended sediments are important is that they can be a source of nutrients. In the early 1980s, intrepid oceanographers from the University of South Florida happened to be in the wrong place at the right time: specifically, on a research vessel at sea as a hurricane approached. They were making measurements of nutrient concentrations at the time. Being smart oceanographers, they did the right thing and found a safe harbor as the storm passed, and being dedicated oceanographers, they went back out to sea to continue their work when it was safe, returning to where they had been before. When they measured the nutrient concentrations again, they discovered that they had increased, particularly near the sea floor.

Sediments, particularly near-shore sediments, can contain a large amount of organic matter. This can be a problem in some places, if bacterial respiration of the organic matter depletes too much oxygen near the bottom. In most areas, however, the oxygen is mainly depleted within the sediments. When the oxygen is gone, the rate of organic matter decay slows down, and therefore sediments can store a lot of organic matter. When storms resuspend these sediments, the organic matter gets re-oxygenated, and this causes increased bacterial respiration and the release of nutrients. More nutrients are derived from the sediment "pore waters" (water that is retained within marine sediments), where they accumulate as organic matter decays in the sediments. The net result of sediment resuspension is a release of nutrients that can foster increased phytoplankton productivity.

Why are suspended sediments important? (continued)

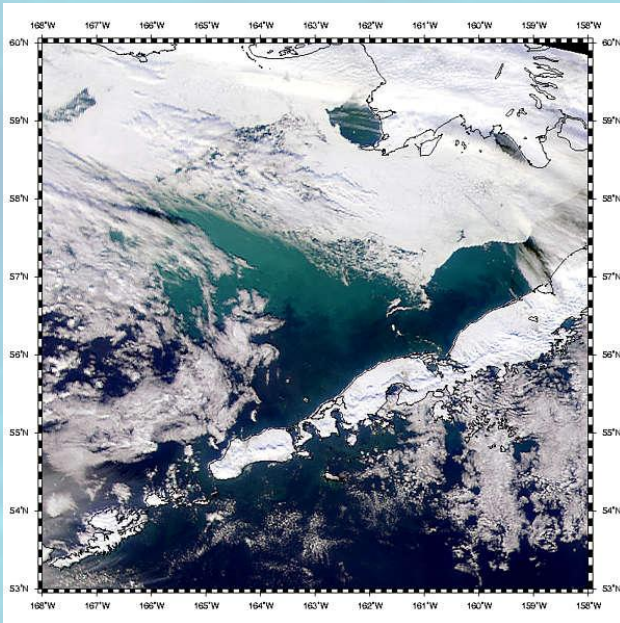
While this process is somewhat innocuous (even though it could provide nutrients for a bloom of toxic phytoplankton), other processes that occur when sediments are resuspended are less innocent. Sedimentary material can possess large surface areas on which metal ions can be absorbed. (This process is particularly important for sediments located near offshore sewage pipes.) When the sediment is on the sea floor, these metals are isolated from the overlying water column. If the sediment is resuspended, the availability of dissolved oxygen and the change in pH between the oceanic waters and the sediment pore waters can cause the release of the metals. This can be a nutrient source for metals like iron, but it is an environmental concern for toxic metals such as mercury, cadmium, and lead.

Finally, resuspended sediments may be composed of minerals that are part of the oceanic carbon cycle, specifically calcium carbonate (CaCO_3). If resuspension transports CaCO_3 from shallow waters to deep oceanic waters, the CaCO_3 will dissolve. This process is discussed in more detail in the *Science Focus!* article "Sedimentia". The sediments in tropical regions (including Cuba, Florida, Bermuda, and the Bahamas) are composed primarily of CaCO_3 , so one effect of tropical storms is to move these sediments from areas where they are "stored" to deep ocean waters where they may influence the geochemistry of the world's oceans. A goal of future research is to quantify the effect of this process on the oceanic carbon cycle.

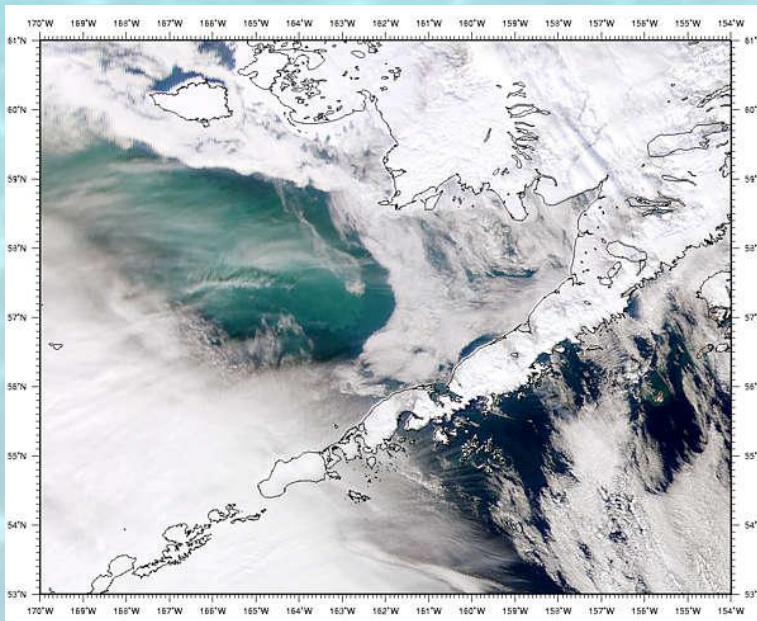
Suspicious Observations in the Bering Sea

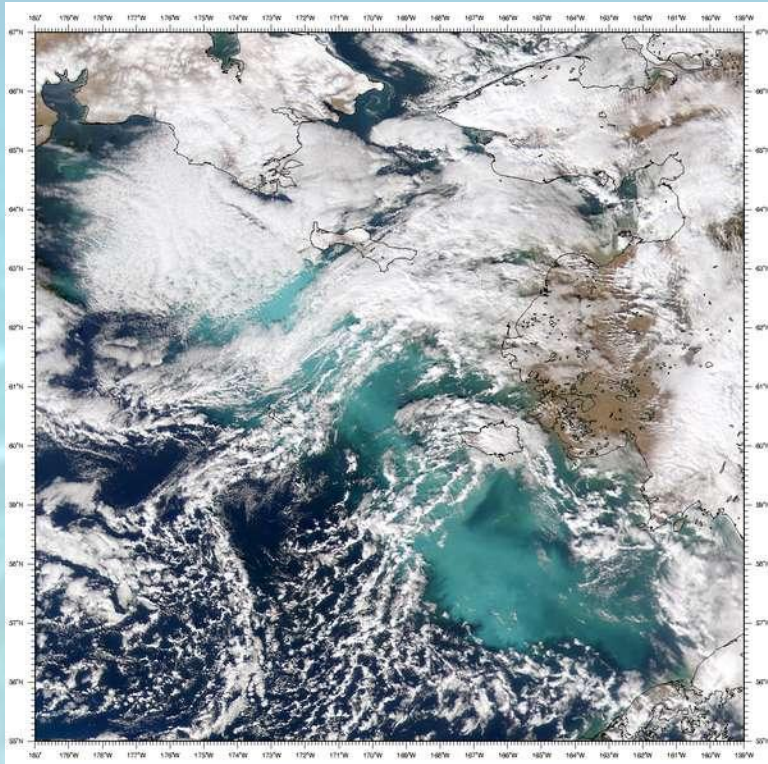
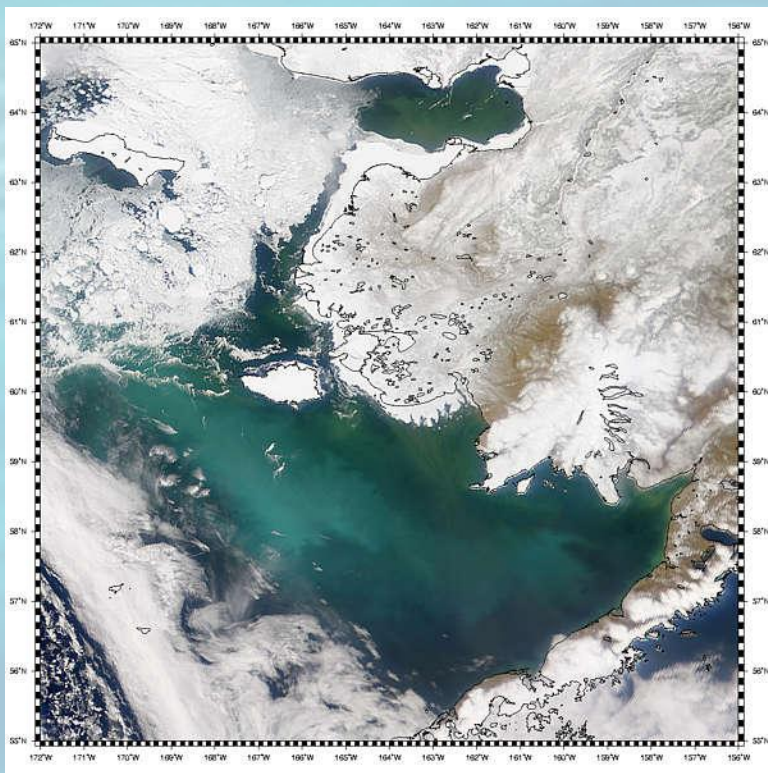
Many different types of marine organisms form structures out of CaCO_3 . In shallow tropical waters, hard corals, coralline algae, and benthic foraminifera are some of the organisms which create CaCO_3 shells or skeletons. In the open ocean, organisms including planktonic foraminifera, pteropods, and coccolithophorids also form CaCO_3 tests or shells or coccoliths. Coccolithophorid blooms, particularly those of the coccolithophorid *Emiliania huxleyi* (*E. hux*) are familiar to both at-sea and remote-sensing oceanographers, because they form characteristic bright blue-white patches that are fairly easy to recognize. Dr. Toby Tyrrell has acquired a collection of remote-sensing images of coccolithophore blooms; see the Links at the end of the article.

At the beginning of the SeaWiFS mission, an unusual and temporary change in the ecosystem of the Bering Sea was taking place. One of the effects of this change was the occurrence of a widespread coccolithophore bloom, which showed up prominently in SeaWiFS images. Over the next few years, SeaWiFS images frequently showed similar patches of bright water in the Bering Sea, which were thought to be indicative of more coccolithophorid blooms. Some examples are shown below and on the next page.



SeaWiFS images of bright waters observed in the Bering Sea in the year 2000. (top) February 8. (bottom) March 2.





SeaWiFS images of bright waters observed in the Bering Sea in the year 2000. (top) April 30. (bottom) October 10.

Marine biologists familiar with *E. hux* began to realize that the supposed blooms occurring in the Bering Sea weren't occurring at the right time or in the proper oceanic environment for such blooms. In particular, in many cases the colored waters were observed in the late autumn and spring (and even occasionally in the winter when the clouds parted)—certainly not the conditions preferred by *E. hux*! The Bering Sea had also shifted back to its normal state, and this normal state does not feature environmental conditions favored by coccolithophorids, either.

So, faced with this intriguing mystery, oceanographers decided to determine (or at least make an attempt) to find out what was causing the bright waters in the Bering Sea. Discovering the answer required hard and painstaking work under difficult conditions—the Bering Sea in winter, a research effort worthy of its own story.

The answer to the mystery appears in the paper "The cause of bright waters in the Bering Sea in winter" by Broerse *et al.*, published in the journal *Continental Shelf Research* (see the Reference section below for the complete citation).

Acknowledgments

We gratefully acknowledge the assistance of Dr. Toby Tyrrell in providing information and images of *Emiliana huxleyi*. Norman Kuring of the SeaWiFS Project and the MODIS Rapid Response Team provided the SeaWiFS and MODIS images shown in this article.

References

[Sediment resuspension by coastal waters: a potential mechanism for nutrient re-cycling on the oceans margins.](#) Fanning, K.A., K.L. Carder and P.R. Betzer, 1982.

Deep-Sea Res., **29(8A)**, 953-965.

[The "CORSAGE" programme: continuous orbital remote sensing of archipelagic geochemical effects.](#) Acker, J.G., C.W. Brown, and A.C. Hine, 1997. *Intl. J. Remote Sens.*, **18(2)**, 305-321.

[The cause of bright waters in the Bering Sea in winter.](#) Broerse, A.T.C., T. Tyrrell, J.R. Young, A.J. Poulton, A. Merico, W.M. Balch, and P.I. Miller, 2003. *Cont. Shelf. Res.*, **23**, 1579-1596.

[Satellite remote sensing observations and aerial photography of storm-induced neritic carbonate transport from shallow carbonate platforms.](#) Acker J.G., Brown, C.W., Hine, A.C., Armstrong, E., and Kuring, N. 2002. *International Journal of Remote Sensing*, 23 (14), 2853-2868.

Related *Science Focus!* Articles

☐ Sedimentia

☐ An Enlightened View of Calcite in the Ocean with MODIS

☐ Seasons and Cycles of Change in the Bering Sea

Links

[Muddy Waters](#) (SeaWiFS data views resuspended sediments in Lake Pontchartrain)

[Metal Remobilisation during Resuspension of Anoxic Contaminated Sediment](#) (Article abstract)

[Satellite images of *Emiliana huxleyi* blooms](#)

[Sediment Resuspension Events Forced by Hurricanes Edouard and Hortense](#)